STUDY OF OVALBUMIN COAGULATION DYNAMICS BY USING UPCONVERSION LUMINESCENCE OF $NaYF_4$:Yb,Er NANOPARTICLES

Ustalkov S.O.,[1] Mohammed A.H.M.,[1] Zakharevich A.M.,[1] Kozyrev A.A.,[2] Sagaidachnaya E.A.,[1] Kochubey V.I.,[1,3] Skaptsov A.A.[1]

[1] *Saratov State University, Russia*

[2] *National Research Nuclear University MEPhI, Russia*

[3] *National Research Tomsk State University, Russia*

Abstract

The work is demonstrated a method to measure the dynamics of the internal temperature of biological tissues and the thickness of a denatured layer during laser thermolysis by measuring the intensities of three luminescence bands of $NaYF_4$:Yb,Er upconversion nanoparticles. A model biological tissue was ovalbumin.

Materials

Study sample was ovalbumin and absorbing phantom contained upconversion nanoparticles $NaYF_4$:Yb,Er. The experiments were carried out using laser (wavelength was 980 nm, beam diameter was 5.1 mm), power meter, spectrometer, and IR imager.

Methods

$$I_\lambda = A_\lambda \exp\left[-\frac{\Delta E_\lambda}{kT}\right] \quad (1)$$

$$\frac{I_{\lambda_1}}{I_{\lambda_2}} = \exp\left[C_{\lambda_1,\lambda_2} - \frac{\varepsilon_{\lambda_1,\lambda_2}}{kT}\right] \quad (2)$$

$$C_{\lambda_1,\lambda_2} = \ln\left[\frac{A_{\lambda_1}}{A_{\lambda_2}}\right]$$

$$\varepsilon_{\lambda_1,\lambda_2} = \Delta E_{\lambda_2} - \Delta E_{\lambda_1}$$

$$I_\lambda = I_\lambda^0 \exp[-\alpha_\lambda l] \quad (3)$$

$$\frac{I_{\lambda_1}}{I_{\lambda_2}} = \frac{I_{\lambda_1}^0}{I_{\lambda_2}^0}\exp[(\alpha_{\lambda_2} - \alpha_{\lambda_1})l] = \exp\left[C_{\lambda_1,\lambda_2} - \frac{\varepsilon_{\lambda_1,\lambda_2}}{kT} + \beta_{\lambda_1,\lambda_2} l\right] \quad (4)$$

$$\beta_{\lambda_1,\lambda_2} = \alpha_{\lambda_2} - \alpha_{\lambda_1}$$

$$\begin{cases} l = \dfrac{1}{\beta_{546,531}} \dfrac{\dfrac{\varepsilon_{546,531}}{\varepsilon_{666,531}}\left(C_{666,531} - \ln\left[\dfrac{I_{666}}{I_{531}}\right]\right) - \left(C_{546,531} - \ln\left[\dfrac{I_{546}}{I_{531}}\right]\right)}{\left(1 - \dfrac{\varepsilon_{546,531}}{\varepsilon_{666,531}}\dfrac{\beta_{666,531}}{\beta_{546,531}}\right)} \\ T = \dfrac{\varepsilon_{666,531}}{k}\left(\dfrac{\left(C_{666,531} - \ln\left[\dfrac{I_{666}}{I_{531}}\right]\right) - \dfrac{\beta_{666,531}}{\beta_{546,531}}\left(C_{546,531} - \ln\left[\dfrac{I_{546}}{I_{531}}\right]\right)}{\left(1 - \dfrac{\varepsilon_{546,531}}{\varepsilon_{666,531}}\dfrac{\beta_{666,531}}{\beta_{546,531}}\right)}\right)^{-1} \end{cases} \quad (5)$$

Results

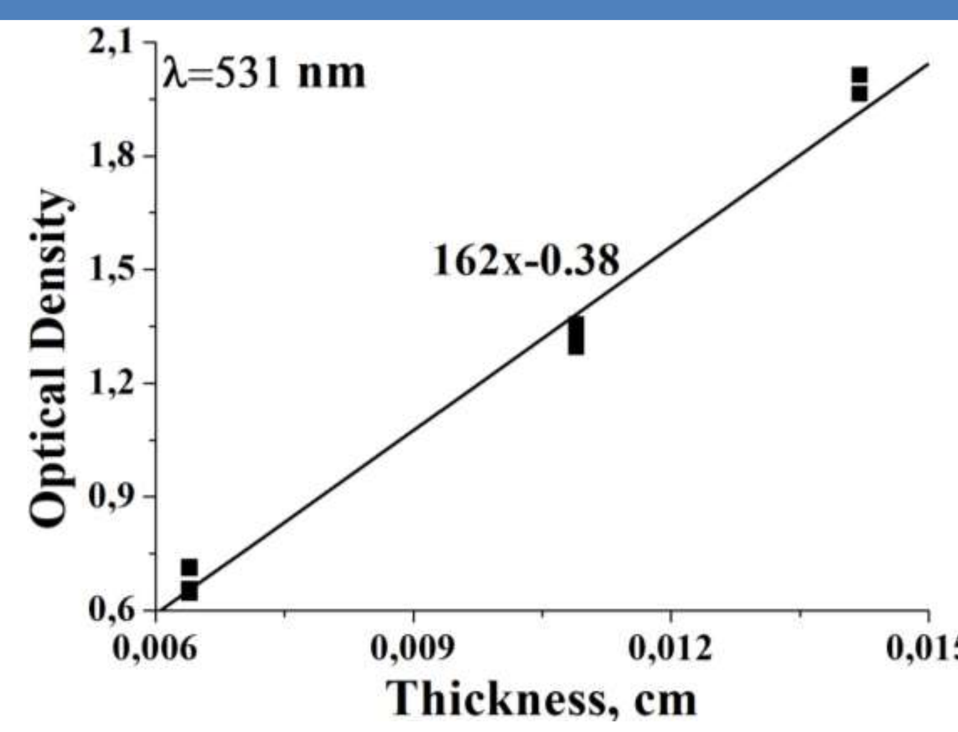

Fig. 1. Dependency between optical density and ovalbumin thickness at 531 nm

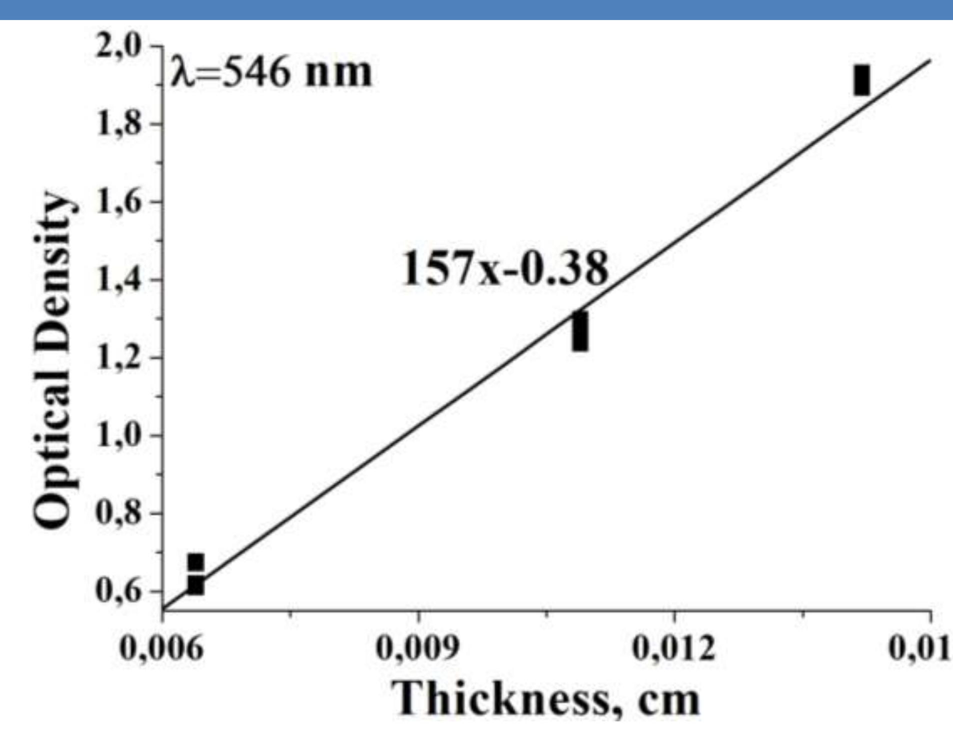

Fig. 2. Dependency between optical density and ovalbumin thickness at 546 nm

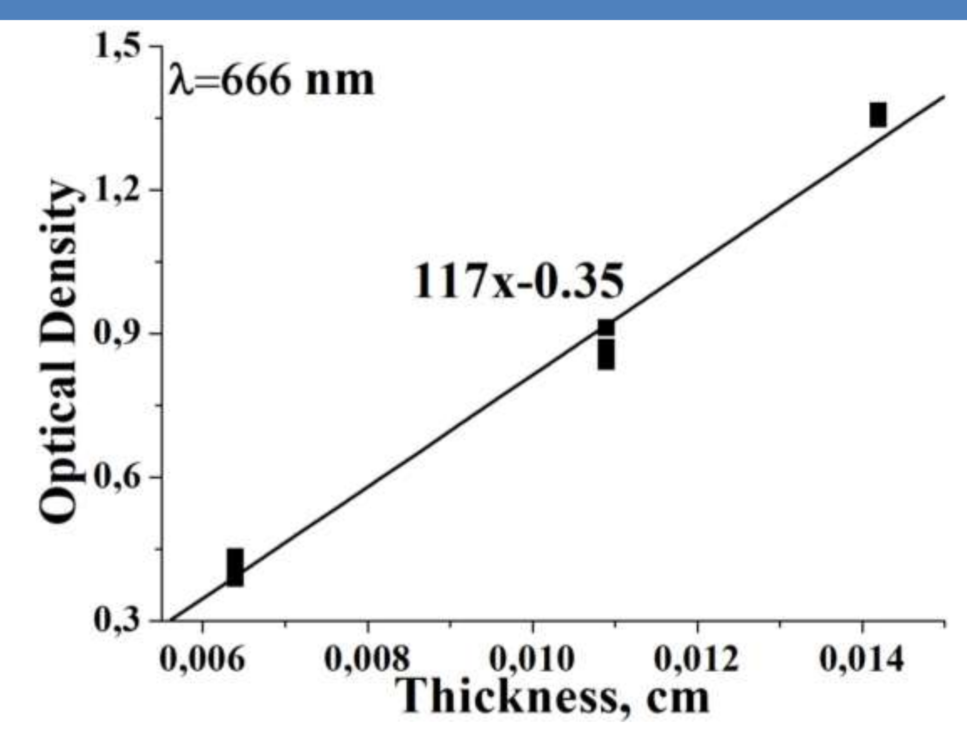

Fig. 3. Dependency between optical density and ovalbumin thickness at 666 nm

λ, nm	531	546	666
α_λ, cm^{-1}	162	157	117

Table 1. Light attenuation of denatured ovalbumin at 531, 546 and 666 nm obtained by eq. (3)

λ_1, nm	λ_2, nm	$C_{\lambda1,\lambda2}$	$\Delta\varepsilon_{\lambda1,\lambda2}$, eV
546	531	–2.331	–0.07846
666	531	–8.912	–0.1896

Table 2. Calibration coefficients for temperature sensing using luminescence of $NaYF_4$:Yb,Er upconversion nanoparticles obtained by eq. (2)

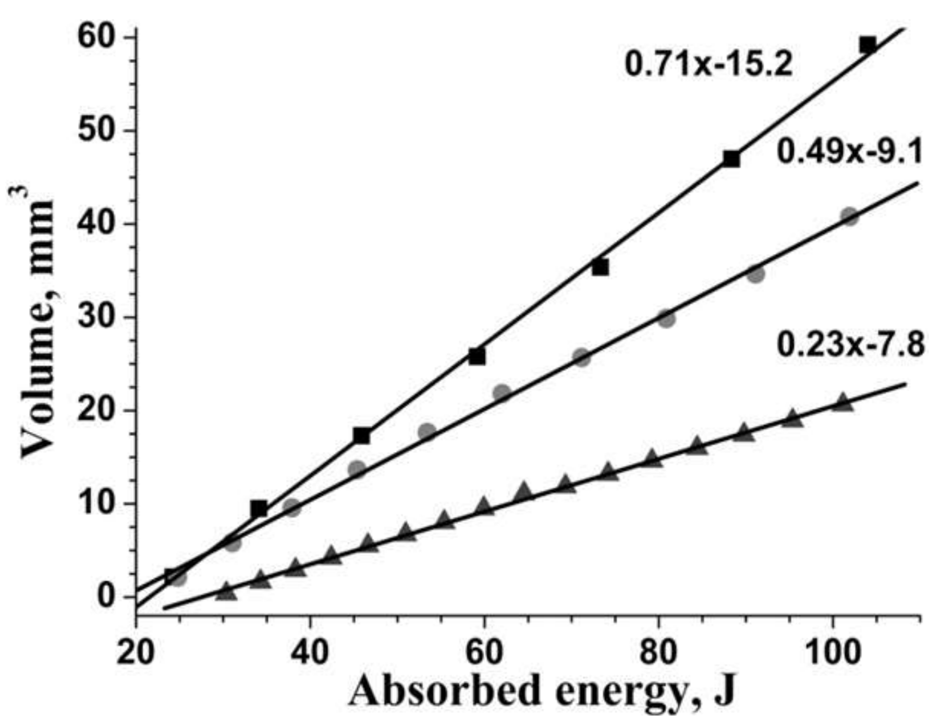

Fig. 4. Dependencies between volume of denatured ovalbumin and absorbed energy for several power densities: ■ – 9.8 W/cm²; ● – 7.3 W/cm²; ▲ – 4.9 W/cm²

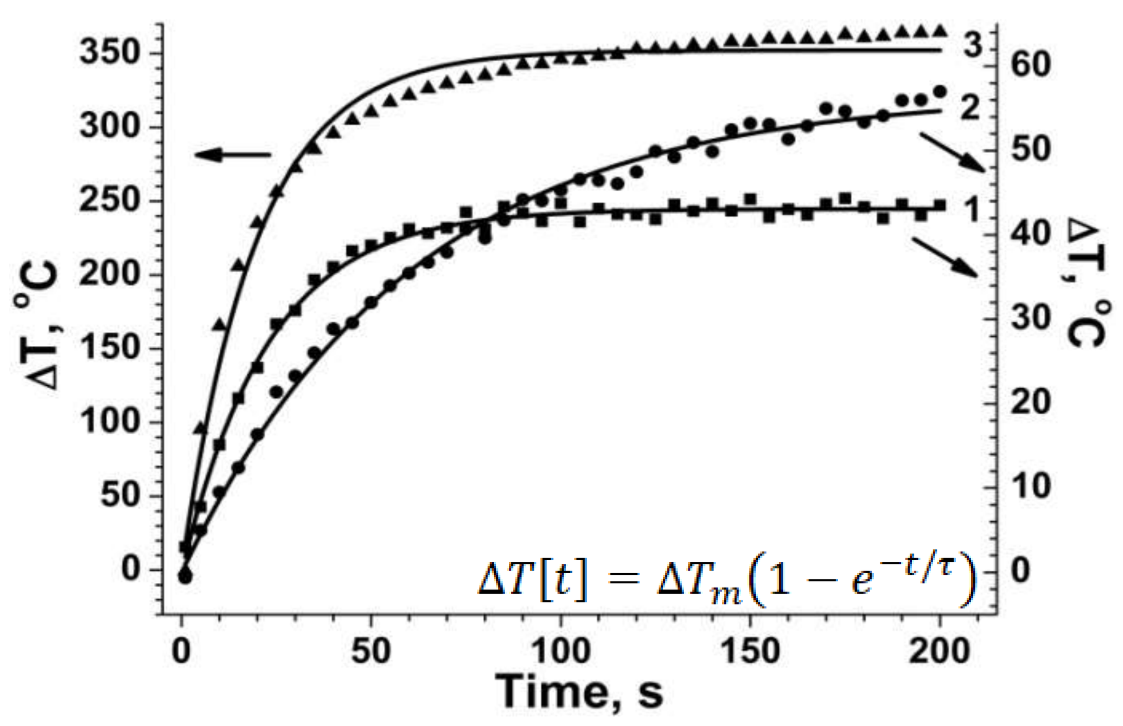

Fig. 5. Relative temperature as time function calculated by: ■ – eq. (5) (right y-axis); ● – eq. (2) for 531 and 546 nm (right y-axis); ▲ – eq. (2) for 531 and 666 nm (left y-axis)

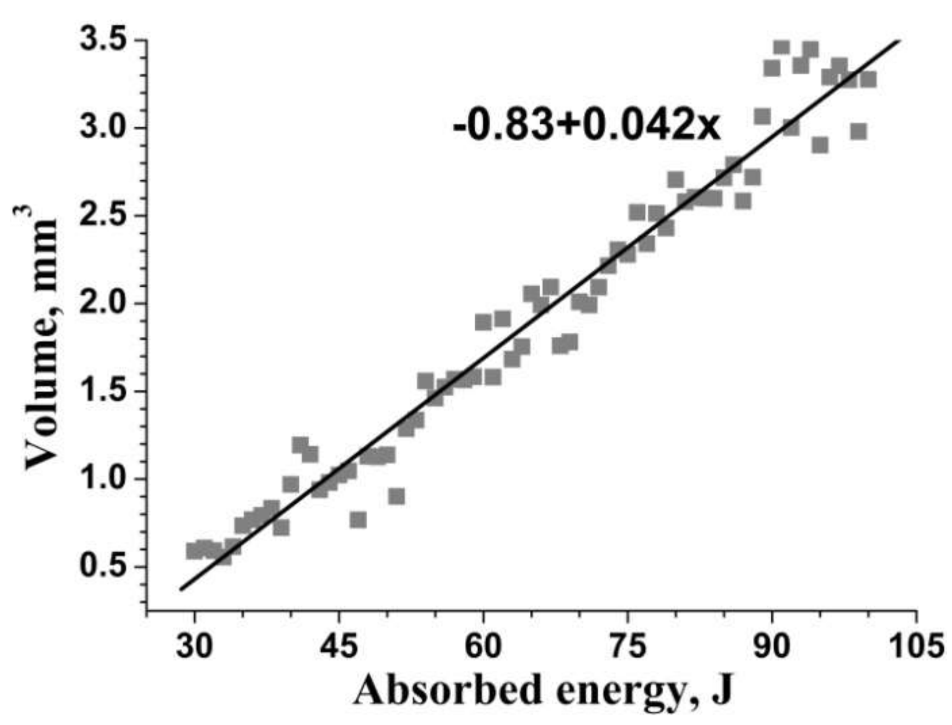

Fig. 6. Dependency between volume of denatured ovalbumin and absorbed energy; the volume were obtained by eq. (5)

Conclusion

The denaturation process introduces distortions in the temperature sensing using the luminescent method. The developed method using three luminescence bands was successfully tested and showed the possibility of simultaneously determining the temperature inside the biological tissue and the thickness of the denatured layer. The volume of denatured tissue is linearly depended on the dose of absorbed energy.

Acknowledgements

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